Atmospheric Research 169 (2016) 147–159

Contents lists available at ScienceDirect

Atmospheric Research

journal homepage: www.elsevier.com/locate/atmos

Daily quantitative precipitation forecasts based on the analogue method: Improvements and application to a French large river basin

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ARTICLE INFO

Article history:
Received 22 May 2015
Received in revised form 31 July 2015
Accepted 18 September 2015
Available online 3 October 2015

Keywords:
Probabilistic quantitative precipitation forecasting
Statistical adaptation
Analogues
ERA-40 reanalyses
Saône river basin

ABSTRACT

This paper presents some improvements of a probabilistic quantitative precipitation forecasting method based on analogues, formerly developed on small basins located in South-Eastern France. The scope is extended to large scale basins mainly influenced by frontal systems, considering a case study area related to the Saône river, a large basin in eastern France. For a given target situation, this method consists in searching for the most similar situations observed in a historical meteorological archive. Precipitation amounts observed during analogous situations are then collected to derive an empirical predictive distribution function, i.e. the probabilistic estimation of the precipitation amount expected for the target day. The former version of this forecasting method (Bontron, 2004) has been improved by introducing two innovative variables: temperature, that allows taking seasonal effects into account and vertical velocity, which enables a better characterization of the vertical atmospheric motion. The new algorithm is first applied in a perfect prognosis context (target situations come from a meteorological reanalysis) and then in an operational forecasting context (target situations come from weather forecasts) for a three years period. Results show that this approach yields useful forecasts, with a lower false alarm rate and improved performances from the present day D to day $D + 2$.

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http://dx.doi.org/10.1016/j.atmosres.2015.09.015
0169-8095/

1. Introduction

Many water-related stakeholders need quantitative precipitation forecasts as reliable as possible to anticipate discharges in river basins several hours or days ahead. For example, French operational flood forecasting services require precipitation forecasts several days ahead to anticipate flood risks (Lacaze et al., 2008), and hydroelectricity power producers need accurate and reliable precipitation forecasts to anticipate the discharge evolution along the regulated rivers and their tributaries in order to perform their activities and to provide safety control (Bompart et al., 2009).

Nowadays forecast uncertainties related to meteorological predictions and implied by modelling processes are more and more taken into account, leading to probabilistic quantitative precipitation forecasts (PQPFs) that provide ensemble forecasts. In particular, this kind of forecast enables to evaluate the risk of extreme events. At least, two approaches for producing PQPFs are commonly used: (i) regional ensemble weather forecasts based on dynamical approaches (e.g. COSMO-LEPS, Marsigli et al., 2005; PEARP, Thirel et al., 2008; EFAS, Thielen et al., 2009; ECMWF-ENS, Miller et al., 2010), (ii) statistical approaches based on a search for analogues (e.g. Obled et al., 2002; Hamill and Whitaker, 2006; Messner and Mayr, 2010; Marty et al., 2012).

The principle of analogue methods (AMs) is to use deterministic meteorological outputs of a target day *D* as an input for a statistical search of similar past days in terms of general circulation patterns. Similarity is measured on a set of relevant predictor variables computed by Numerical Weather Prediction (NWP) models. Finally the analogue situations selected are used to produce a sample of observed daily precipitations, which provides a probabilistic forecast for the day *D*.

The AMs assume a relationship between large-scale variables (predictors) and a local-scale target variable (predictand). Different predictors can be found in the literature. Table 1 presents a short description of a selection of representative models developed to predict precipitation fields under various climates. Note that this table does not include methods using combination of predictors in linear regression to estimate predictands. One can note that the number of predictors may differ from one region to another. Timbal et al. (2008) suggest defining combinations of predictors adapted for each season and each climatic region.

The predictors can be divided into two categories. Most AM developments deal with one or more low flow atmospheric fields, i.e. descriptors of the meteorological state of the atmosphere at synoptic scale and a set of geopotential heights is usually chosen. The number of geopotential heights and their corresponding pressure level varies from one study to another: Altava-Ortiz et al. (2006) used three geopotential heights at 500, 850 and 1000 hPa to estimate precipitation amounts for one major heavy rainfall event in Catalonia (Spain) while Diomede et al. (2008) selected the geopotential at 500 hPa to estimate precipitation in Northern Italy. Following Bontron and Obled (2005), Horton et al. (2012) and Chardon et al. (2014) selected analogous situations based on geopotential heights at 500 and 1000 hPa-level in Switzerland and in France, respectively.

The second category of predictors is made of moisture related variables with among them, the large-scale precipitation outputs PRCP from NWP models (e.g. Diomede et al., 2014; Turco et al., 2011).

Table 1
Predicators and study areas for a selection of AM applications (TCW: total column of water; RH: relative humidity, SLP: sea level pressure; Z: geopotential height; T: temperature, SH: specific humidity; PRCP: total precipitation; VV: vertical velocity; additional numbers indicate the related atmospheric level in hPa).

Reference	Study area	Predictors
Altava-Ortiz et al. (2006)	Catalonia (Spain)	Z850, Z1000
Barrera et al. (2007)	Catalonia (Spain)	Z500, Z850, Z1000, humidity at 1000 hPa
Bliefernicht and Bárdossy (2007)	Western Germany	Z700, Z1000, SH700, westerly wind at 700 hPa
Bontron and Obled (2005)	South-Eastern France	Z500, Z10000, TCW, RH850
Cannon (2007)	British Columbia (Canada)	SLP, RH700, horizontal wind components at 700 hPa, Z500
Chardon et al. (2014)	France	Z500, Z1000
Dayon et al. (2015)	France	SLP, 2 m air temperature TAS, lifted condensation level, moisture flux at 850 hPa, totals total index, SH850
Diomede et al. (2008)	Reno river basin (northern Italy)	Z500, VV700
Diomede et al. (2014)	Northern Italy, Germany, Switzerland	PRCP
Gibergans-Báguena and Llasat (2007)	Catalonia (Spain)	Z700, Z1000, precipitable water mass in 700–500 hPa stratum, relative temperature at 850 hPa, instability indices (lifted index and K index), level at which the temperature is 0 °C, Convective Available Potential Energy, potential temperature gradient in 850–700 hPa stratum, equivalent potential temperature gradient of the surface − 950 hPa stratum.
Horton et al. (2012)	Swiss Alps (Switzerland)	Z500, Z1000
Marty et al. (2012)	Southern France	Z500, Z1000, TCW, RH850
Mehrotra et al.(2014)	Sydney region (Australia)	T700, T850, meridional gradient of Z850, VV500, VV850, Z850
Osca et al. (2013)	Spain	SLP, T850
Palatella et al. (2010)	Apulia region and Po Valley (Italy), Ebro river basin (Spain), Antalya province (Turkey)	SLP, T500
Ribalaygua et al. (2013)	Aragon (Spain)	Speed and direction of the geostrophic wind at 500 hPa and at 1000 hPa
Salathé (2003)	Washington and Oregon states (USA)	Z1000
Schenk and Zorita (2012)	Northern Europe and the Baltic Sea region	SLP
Schmidli et al. (2007)	Alps (France, Germany, Swiss, Italy, Austria)	Geostrophic wind (direction and velocity) at 1000 and 500 hPa
Teng et al. (2012)	South-Eastern Australia	SLP, PRCP, SH850, Surface max temperature Tmax, T850, zonal and meridional wind components at 850 hPa
Themeβl et al. (2011)	Austria	27 variables
Timbal et al. (2003)	Western France	SLP, Z1000, Z500, T850, Z1000–Z500, TCW
Timbal et al. (2008)	Australia	SLP, PRCP, SH850, RH850, RH700, Surface max temperature Tmax, T850, zonal wind components at 850 hPa, meridional wind components at 700 hPa and 850 hPa
Turco et al. (2011)	Spain	PRCP
Wetterhall et al. (2005)	South-central Sweden	SLP
Wu et al. (2012)	Southeastern Mediterranean	SLP;H700; T700;U850; V850
Zorita and von Storch (1999)	Spain, Portugal, Southern France, Northern Morocco, Northern Algeria	SLP